Detector Triggers and Burst Populations

David Band (GLAST SSC—GSFC/UMBC)

WHAT IS BURST DETECTOR SENSITIVITY?

- **A detector's sensitivity is the threshold intensity at which a burst could have been detected.**
- **Rate trigger—the standard trigger looks for statistically significant increases in the detector's count rate**
  - **The counts are binned over an energy range □E and an accumulation time □t.**
  - **The background is estimated from the counts accumulated over a longer period beforehand. The fluctuation scale □ is the square root of the expected background in □t & □E.**
  - **A statistically significant increase is a predetermined number of □.**
- **Complications:**
  - **May require a trigger in multiple detectors; for flat detectors with different orientations this introduces a variable threshold**
  - **After a rate trigger, may require that imaging finds a point source**

HOW IS SENSITIVITY MEASURED?

- The most accurate sensitivity measure is the intensity the trigger measures, i.e., the peak count rate averaged over □E & □t. But counts=instrumental, photons=physical. Because of imperfect efficiency and energy resolution, a spectrum is needed to translate this into a peak photon flux. Why translate to □E, not some other energy range?
- Note that peak photon flux may not be the most interesting intensity measure physically.
- Because bursts are not constant for seconds, and burst lightcurves differ at different energies, peak fluxes over □E_1 & □t_1 and □E_2 & □t_2 cannot be compared directly.
- A numerically better (=smaller) sensitivity over a different □E & □t does not mean that fainter bursts can be detected.
- The number of bursts and their type depends on the detector and its trigger.

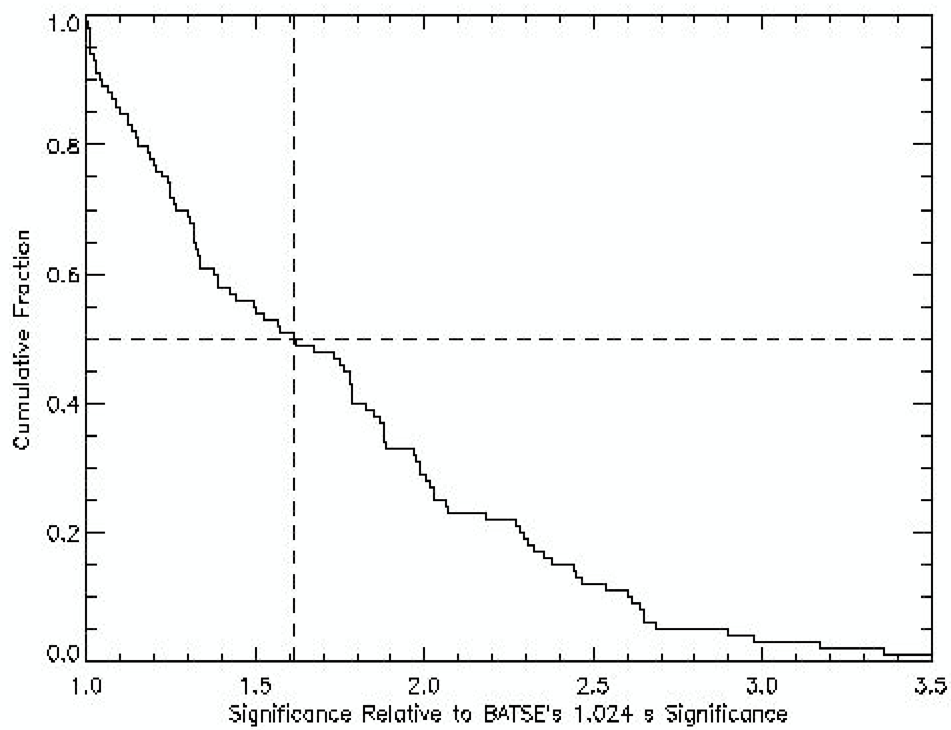
HOW MANY BURSTS ARE THERE?

- Since the entire burst population has not been sampled, the answer depends on ΔE & Δt.
- BATSE provided the best determination of the burst rate.
  - Initial report of 800 bursts/yr/sky underestimated the observing efficiency
  - Current number is 666 bursts/sky/yr above BATSE's threshold
  - BUT, this threshold was not sharp. BATSE was ~82% complete above ϕ=0.3 ph/cm^2/s.
- Correcting for completeness, etc., the burst rate is 550 bursts/yr/sky for Δt=1.024 s and ΔE=50-300 keV above ϕ=0.3 ph/cm^2/s.
  - BATSE actually had Δt=0.064, 0.256, and 1.024 s.
  - Usually ΔE=50-300 keV, but other energy bands tried.
- But what does this mean in terms of hard bursts? Soft bursts? Long bursts? How can we estimate the burst rate of a detector with different energy sensitivity (e.g., Swift)?

DEPENDENCE ON Δt

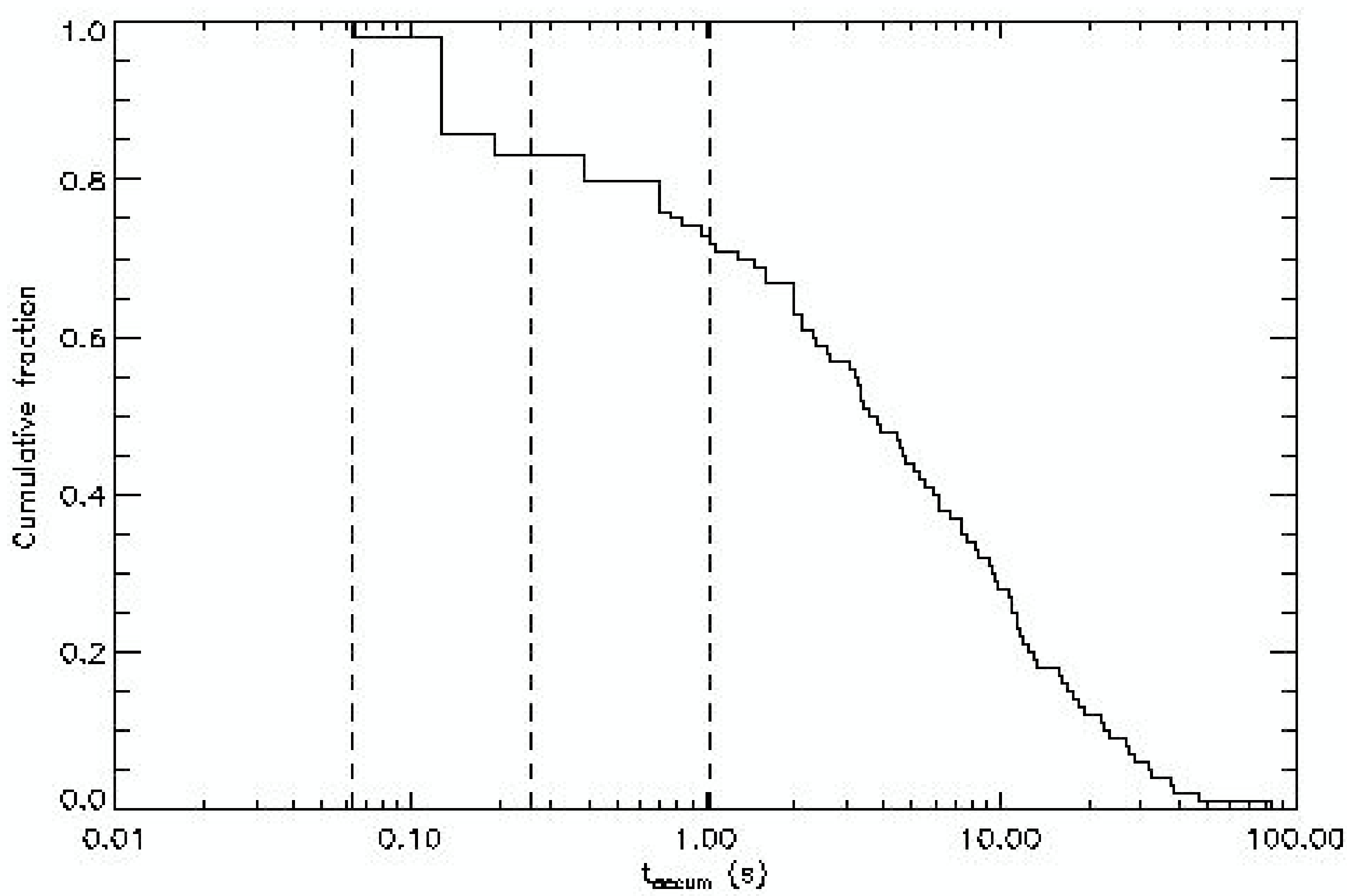
- Usually trigger sensitivity 1/ Δt
- But peak fluxes are usually smaller on longer timescales
- Therefore, increasing Δt does not mean that bursts a factor of Δt can be detected
- Could there be populations of very long or very short bursts that are not detected?
- Studies of untriggered BATSE bursts did not find many very long bursts.
- A study of the 100 brightest BATSE lightcurves using all possible Δt shows:

SENSITIVITY FOR ANY Δt



The average increase in sensitivity relative to Δt=1 s is only a factor of 1.6!

t OF MAXIMUM SENSITIVITY



There were not a large number of bursts where the greatest sensitivity was for small t.

ENERGY DEPENDENCE

- How do we compare detectors with different efficiencies and trigger ΔE?

- Use a fiducial peak photon flux F—i.e., always use the same energy band.
  - A spectral shape must be assumed
  - I propose 1-1000 keV to cover hard and soft spectra
- Study sensitivity as a function of the spectrum's hardness. Burst spectra can be approximated as

  $$N \propto E^{\alpha}\exp[-E/E_0] \text{ at low energy}$$

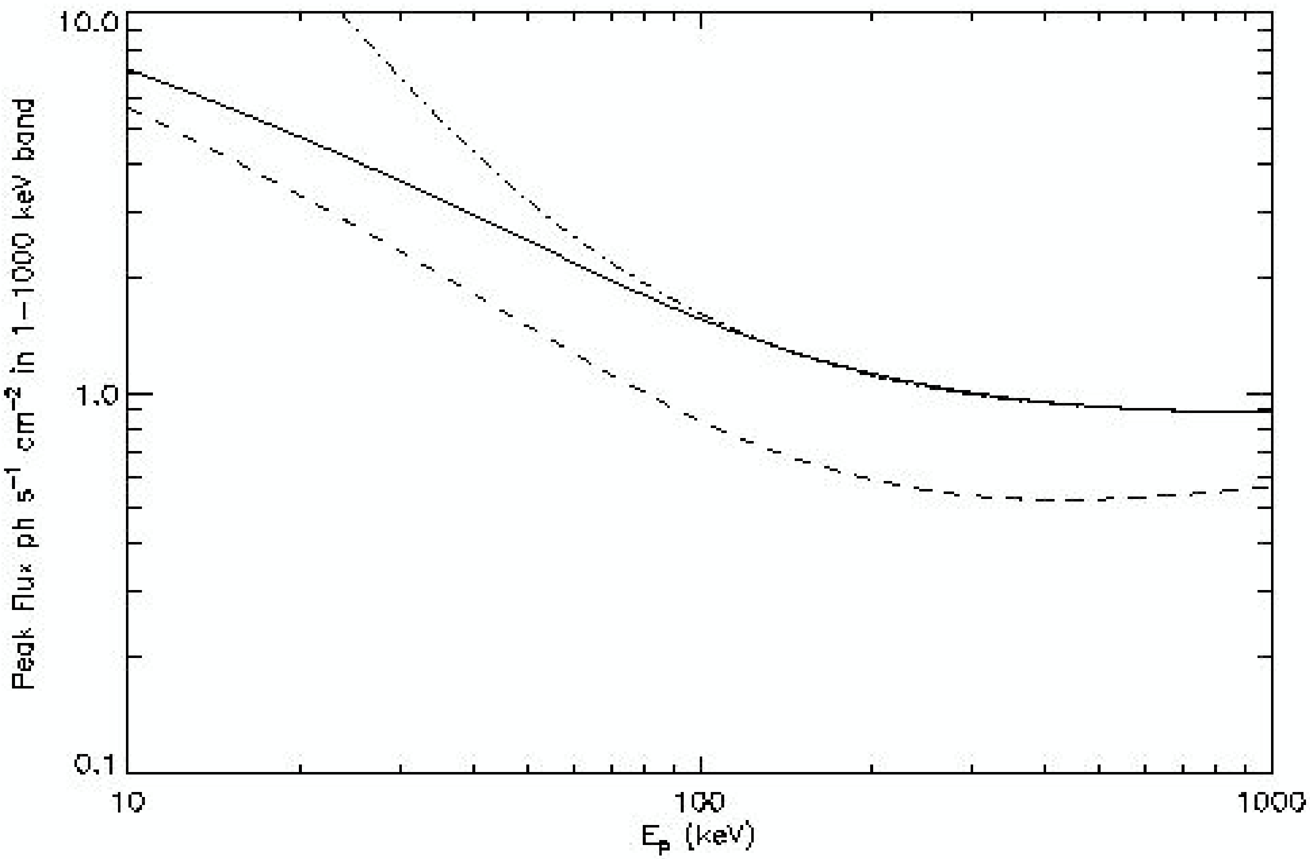
  $$N \propto E^{\beta} \text{ at high energy}$$

  The peak of $E^2N \propto \nu f_\nu$ occurs at $E_p=(2+\alpha)E_0$. E_p is a measure of spectral hardness.
- To eliminate the dependence on Δt, use Δt=1 s.

DETECTOR SENSITIVITY & BURST POPULATIONS

- Bursts will populate the E_p-F plane, while the detector sensitivity is a curve through the E_p-F plane.
- There remains a residual dependence on the high and low spectral indices, □ and □.
- Because of varying background and (in some cases) the requirement that ≥2 detectors trigger, detector sensitivity will vary with time and over the FOV. I use the maximum sensitivity (minimum F).
- E_p and F are for the peak of the lightcurve. Unfortunately, rarely are spectral fits presented for this peak. Thus we do not have the data to populate the E_p-F plane with bursts. But hardness ratio-intensity plots indicate general trends.

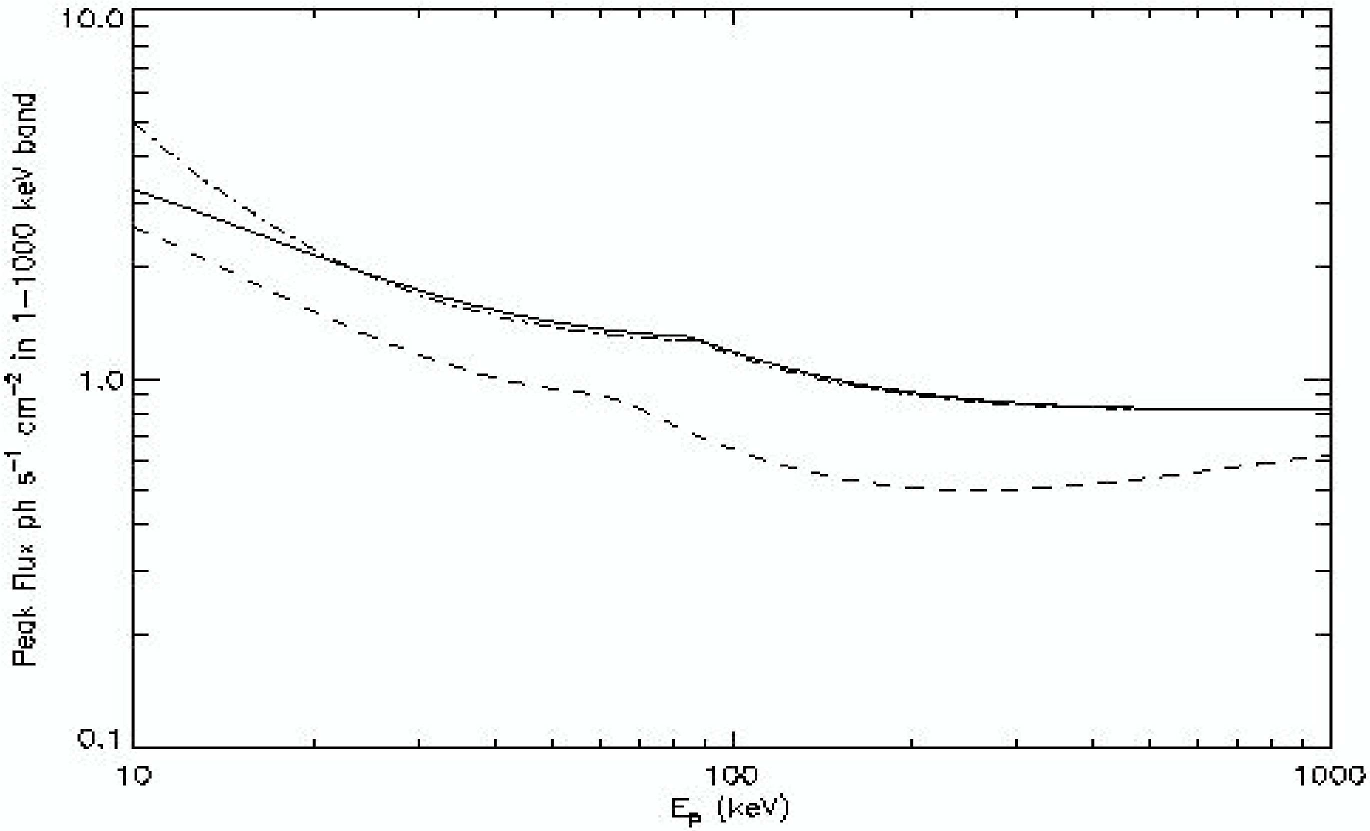
BATSE—THE REFERENCE MISSION



Solid line—□ = -1, □ = -2; dashed line—□ = -0.5, □ = -2;

dot-dashed line—□ = -1, □ = -3.

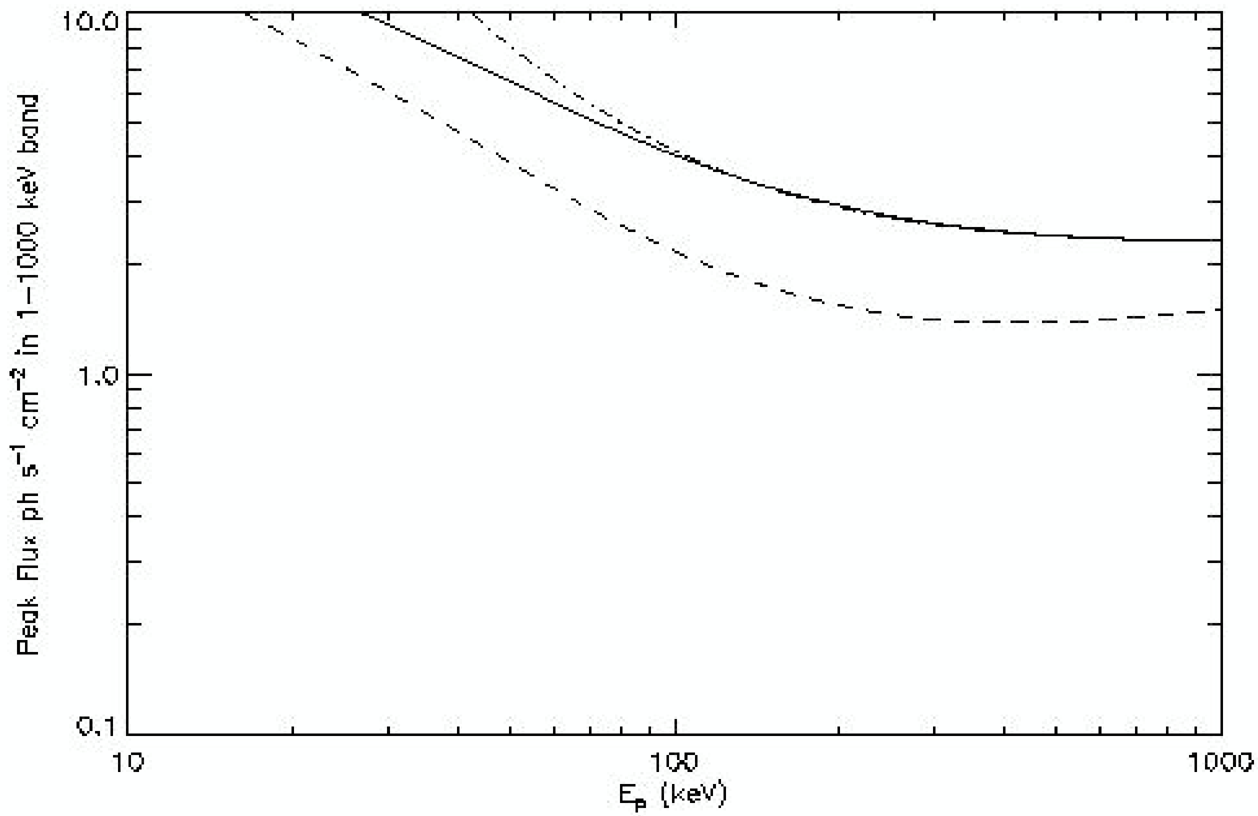
SWIFT—INCREASED LOW E SENSITIVITY



Solid line—α = -1, β = -2; dashed line—α = -0.5, β = -2;

dot-dashed line—α = -1, β = -3.

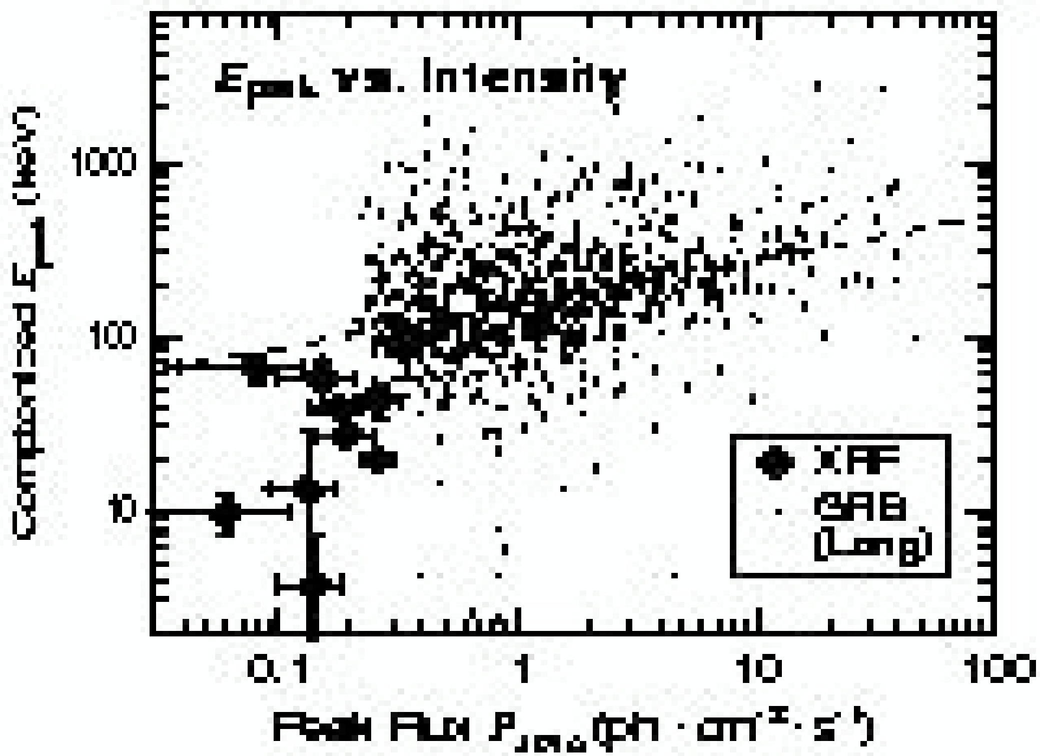
GBM-NaI—SMALL DETECTOR



Solid line—□ = -1, □ = -2; dashed line—□ = -0.5, □ = -2;

dot-dashed line—□ = -1, □ = -3.

BURSTS IN THE E_p-F PLANE

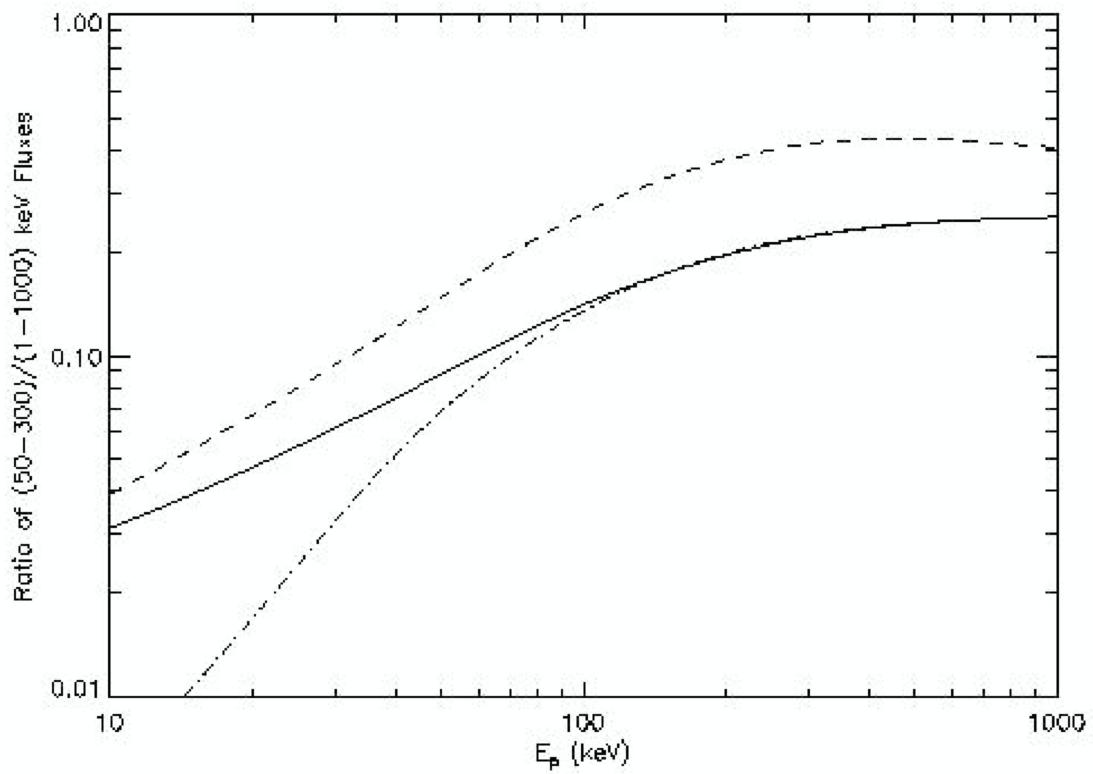


Kippen *et al*., 2002, Woods Hole GRB Workshop. Note that F and E_p are reversed.

SUMMARY

- Detector sensitivities with different sets of ΔE and Δt cannot be compared directly.
- A variety of accumulation times Δt will increase a detector's sensitivity, but not by large factors.
- Detector comparisons should be done in the E_p-F plane.
- BATSE found that the burst rate is 550 bursts/yr/sky for Δt=1.024 s and ΔE=50-300 keV above Φ=0.3 ph/cm^2/s. This translates into a rate for a region of the E_p-F plane.
- Swift and BATSE will have comparable sensitivities above E_p=100 keV, while Swift will be much more sensitive at low energies.
- As expected, the GBM NaI detectors will be significantly less sensitive than BATSE.
- The LAT will be interested in high F, high E_p bursts.

FLUX RATIO FOR DIFFERENT ENERGY BANDS



Solid line—□ = -1, □ = -2; dashed line—□ = -0.5, □ = -2; dot-dashed line—□ = -1, □ = -3.

Expected GBM Detection Rate

- **Assume triggering on 50--300 keV band in Δt=1s time bins. A 4.5σ increase in the 2nd brightest detector is equivalent to ~6.5σ in the LAT FOV. This results in a threshold peak flux of Φ_0=0.814 ph s^{-1} cm^{-2}.**

- **Based on the BATSE-observed burst rate $N_{sky}=(0.814/0.3)^{-0.8}\times 550$=~250 bursts/sky/year**

- **Different Δt increases detection rate by ~50%, giving N_{sky}=~370 bursts/sky/year**
  - **Within 55° FOV ~80 bursts/year**
  - **Within 72.5° FOV ~130 bursts/year**
  - **Within ~1/2 sky, ~185 bursts/year.**

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Empirical LAT Detection Rate

- Extrapolate BATSE spectra to LAT energy band:
  - 1) The Preece *et al*. (2000) catalog of ~5500 time resolved spectral fits from 156 high flux, high fluence bursts
  - 2) The spectral fits to ~1400 bursts by Mallozzi *et al*.
- The number of bursts is normalized by BATSE rate. The high energy spectral index is forced to be <-1.8. Spectral extrapolations are folded with the LAT effective area for different inclination angles, and the results are integrated over inclination angle.
- Limitations: too few strong bursts, incompleteness at faint end, lack of spectral resolution.

Empirical Prediction